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A SUMMARY OF FINDINGS OF THE ECOLOGICAL SURVEY OF WHITE OAK CREEK, ROANE COUNTY, TENNESSEE, 1950-1953

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A SUMMARY OF FINDINGS OF THE ECOLOGICAL SURVEY OF WHITE OAK CREEK, ROANE COUNTY, TENNESSEE, 1950-1953

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INTRODUCTION

The Ecological Survey of White Oak Creek was established as a cooperative program between the Tennessee Valley Authority and the Atomic Energy Commission for the investigation of the physical and biological effects of radioactive effluents on the environment of the area occupied by and contiguous to the operations of the Commission at Oak Ridge, Tennessee. Despite the fact that the more hazardous liquid wastes from the Oak Ridge National Laboratory -- wastes which contained large concentrations of fission products and uranium, and low concentrations of transuranic elements -- were placed in underground storage tanks, it was thought that seepage from the tamks and the routine disposal of low-level radioactive waste into White Oak Creek might have a deleterious effect upon the flora and fauna. In addition, if the organisms manifested a certain degree of tolerance, some economies in waste disposal might be accomplished.

The Tennessee Valley Authority was selected to conduct this study because of its interest in stream sanitation, its employment of properly qualified personnel, and its geographic proximity to Oak Ridge.

The survey period extended from June 1950 until July 1, 1953.

Office space and laboratory facilities for survey personnel were provided by the Health Physics Division of the Oak Ridge National Laboratory during the entire period of the work, and members of that division acted in an advisory capacity and assisted materially in the planning and execution of various phases of the program.

The studies included in the Survey were divided into three main categories — botany, limnology, and fishery biology.

The botanical studies included (a) a collection of bryophytes and vascular plants in the area; (b) a study of the successional aspects of the vegetation; and (c) a study of the accumulation of radiomaterials in as many different kinds of plants as feasible, along with radiochemical or other analyses required to determine which radionuclides were metabolized by the plants.

The studies in limnology included (a) a physical and chemical survey of the waters of White Oak Creek and Lake, together with studies of the normal limnological biota; (b) the occurrence, magnitude, and duration of plankton pulses; and (c) a study of the accumulation of radiomaterials by the planktonic organisms and other invertebrate forms, together with suitable analyses to determine which radioelements had been concentrated by the different organisms.

The scope of the program for fishery biology was expanded to incorporate studies on all vertebrate organisms, and included (a) six semiannual estimates of the size and composition of the fish population of White Oak Lake, followed by the eradication of the existing fish population by the use of rotenone to verify the results of the netting studies; (b) the dissection of fishes in an effort to establish the percentage composition, by weight, of the various tissues in the body; (c) the food habits of some fishes as determined by analyses of their stomach contents; (d) the accumulation and selective concentration of radiomaterials in the different tissues of individuals of the various classes of vertebrates; (e) radiochemical analyses of selected samples of tissues to determine the amounts and identity of the radioelements accumulated; and (f) the banding and releasing of migratory waterfowl in an effort to maintain some surveillance over the movements of birds that frequented the area.

During the course of the Survey, the following numbers of plants and animals were identified: 38 species of bryophytes, representatives of 93 genera of algae, 392 species of vascular plants, 16 protozoans, 1 poriferan, 1 coelenterate, 2 flat worms, 1 gastrotrich, 25 rotifers, 5 nematodes, 1 tardigrade, 2 bryozoans, 6 annelids, 184 arthropods, 9 molluscs, and 228 chordates. No particular attempt was made to collect and identify the terrestrial insects. Even from this incomplete list of 523 plants and 481 animals, it is evident that there are a great many individual biological factors which contribute to the ecology of the area.

Such a vast array of flora and fauna, when coupled with the various edaphic, physical, and climatological factors, made it impossible, in the time allotted, to study all the biological groups in detail. For this reason, only those organisms and communities which were believed to best exemplify the over-all picture were selected for study. However, it is important to know the relationships between the aquatic plants and animals because the microscopic flora and fauna frequently serve as food for the larger animals. A detailed study of these aquatic food chains could shed considerable light on the capability of one organism to selectively concentrate different radionuclides and perhaps pass them on to some predatory species. For instance, a benthic form, such as a larval chironomid, could selectively concentrate radiophosphorus to a fairly high degree. If, however, that radioelement was not in a suitable form to be assimilated by a fish which fed upon the larva, the radiophosphorus would not be accumulated in the tissues of the fish. Similarly, if the larva did not have the tendency to selectively accumulate large quantities of radiostrontium and the fish did have that tendency, the fish, by consuming very large numbers of the larva and by utilizing all the radiostrontium ingested, could accumulate relatively large amounts of that element. If the radiostrontium were in a form such that both the larva and the fish which fed upon the larva could assimilate and selectively concentrate it, the over-all factor of selective accumulation might be very large.

Although food chains were not studied in detail, it is believed that sufficient information was obtained during the Survey upon which to base general assumptions regarding the effects of radioactive waste materials on the flora and fauna of a selected area, and to recognize the importance and necessity of a continuing research program.

DESCRIPTION OF THE AREA

White Oak Creek, a tributary to the Clinch River in Roane County, Tennessee, has a drainage area of 3850 acres. The topography is typical of the Ridge and Valley Province of the eastern part of the state. The underlying strata are principally limestones, dolomites, sandstones, shales, and siltstones of Cretaceous and Ordovician origin (Stockdale, 1951).

White Oak Creek rises from several sources located on the southeastern slope of Chestnut Ridge and between Chestnut and Haw Ridges. The main stream flows in a southwesterly direction across Bethel Valley over limestones of the Chickamauga group to Haw Gap just south of the site of the Oak Ridge National Laboratory. The stream flows through Haw Gap over the sandstones and shales of the Rome formation and enters Melton Valley where it crosses a region of Conasauga shale until it empties into the Clinch River at mile Cl. 20.8. Along its course it receives several tributaries, the largest of which is Melton Branch. That branch rises in the eastern end of Melton Valley and empties into White Oak Creek just above the upper end of White Oak Lake.

White Oak Lake is an impoundment of the waters of White Oak Creek. The dam consists of a fill on a highway, 0.6 mile upstream from the mouth of the creek, which was in existence for some time before the impoundment of the lake. In 1941, the highway fill was raised to its present level by the Tennessee Valley Authority and the present concrete culvert was installed. (Smith, 1945). During the summer of 1943, a cofferdam of interlocking steel sheet piling was driven around the upstream side of the culvert and the spillway was closed in October of that year. A vertical sliding gate, four feet by six feet, with a top elevation of 750 feet above mean sea level, is used to control the level of water in the lake. Another gate, four feet square, is fitted into the piling near its base and serves to completely drain the lake. Above an elevation of 750 feet the water spills freely over the top of the piling. At full pool the lake extends about a mile upstream from the face of the dam and has an area of 44.19 acres (Fry, 1953).

The lake was designed to serve as a delay in the water stream between the Laboratory and the Clinch River to permit decay of short-lived radio-isotopes and as a holdup point in the case of Laboratory operations which lead to the discharge of unusual quantities of radioactive waste. Inasmuch as one function of the lake was that it should serve as a final settling basin for waste effluents from the Oak Ridge National Laboratory, it is rarely kept at full pool. Rather, the water level is maintained at an elevation of approximately 748 feet, at which level the lake has an area of 35.87 acres. For purposes of this survey, that pool level was considered as normal.

When the lake was impounded, no attempt was made to clear any of the timber or brush from the ponded area. As a result, much of the upper end of the lake has become badly overgrown with willows and other woody plants; many dead trees, flooded out by the impounded water, either remain standing or have toppled over. Old barbed-wire fences are still present in parts of the lake along with an abundance of waterlogged debris which is scattered over much of the present lake bottom. The presence of this sunken debris caused considerable difficulty in the setting and lifting of nets, in seining, and in other operations pertinent to the execution of an aquatic survey.

Two small earthen fills were placed across White Oak Creek, at distances of 2.0 and 2.27 miles above the mouth of the creek (Setter and Kochtitzky, 1950) in order to form impoundments which would serve as preliminary settling basins to White Oak Lake. The construction of the lower fill caused an impoundment of water in a rather extensive marshy area which has been called the Intermediate Pond. Information supplied by J. S. Cheka of the Oak Ridge National Laboratory places the time of construction for both fills either late in 1943 or early the following year. Both fills failed during a flood following the heavy rainfall of September 1944(Smith, 1945). However, much silt had already accumulated in the Intermediate Pond where it remains intact with much of the original earth fill.

White Oak Creek receives the waste effluent from the Oak Ridge National Laboratory from a series of sources located at 2.34 and 3.0 miles above its mouth (Setter and Kochtitzky, 1950). The principal source of effluent is through the Settling Basin which empties through a weir box directly into the creek at a point about 2.54 miles above the Clinch River. The average volume of effluent from the Settling Basin, based on figures compiled by the Chemical Separations Department, Operations Division, Oak Ridge National Laboratory, was approximately 650,000 gallons per 24-hour period during 1953, a decrease of about 11 per cent from that of 1952. In addition to the above-mentioned effluent, the daily output from the retention ponds for 1953 was about 17,000 gallons. The point of effluent from the Settling Basin serves, for purposes of this report, as a dividing line between the upper (uncontaminated) portion of White Oak Creek and the lower (contaminated) section.

The waste effluent which enters White Oak Creek consists of a heterogeneous mixture of chemical wastes resulting from laboratory, pilot-plant, and full-scale operations. Some of these wastes are radioactive and some are not. Part of the radioactivity is due to fission products, uranium, and transuranic elements, and part to induced radioactivity from the processing of various materials in isotope preparation. In addition to these industrial wastes, there is sewage effluent; the sewage has undergone primary treatment (sedimentation) and chlorination.

A considerable portion of the drainage area of White Oak Creek was used for agricultural purposes prior to 1942. According to Fry (1951), about 60 per cent of the area was covered with forest at that time and the remainder consisted of old fields in various stages of ecological succession. Judging by the present cover types, some of the old fields have been abandoned for at least 50 years, some having stages of succession from weeds and grasses to mature pines and hardwoods in the overstory. In addition to this natural succession, several pine plantings were placed by the Civilian Conservation Corps about 20 years ago.

During the course of the Survey, extensive construction was under way on the Laboraotry site. As a result, many denuded areas were formed, and these, coupled with the high annual rainfall, resulted in considerable amounts of silt being carried into the streams and ultimately into White Oak Lake. Consequently, the waters of the lake were almost constantly muddy during the early part of the Survey. As soon as it was feasible, the denuded areas were seeded and mulched, and during the past year or so (1953 and early 1954) the waters of the lake have remained relatively clear.

The climate is usually characterized by relatively mild winters and hot summers. The average annual rainfall is about 52 inches and is fairly evenly distributed over the year. During the Survey, exceptional periods of precipitation, drought, and low temperature were recorded. The summer of 1950 was marked by unusually heavy rainfall which caused luxurious plant growth. The fall of 1950 was mild until the end of November when the temperatures, accompanied by heavy snowfall, were the lowest recorded in 80 years. At that time White Oak Lake became completely covered with ice and that condition persisted for about four weeks. The cold weather continued well into the spring and the development of the spring flora was delayed until late April. The summer of 1951 was hot and dry and the drought extended through July and August. During that period the vegetation suffered severely. The fall of 1951 was drier than normal and the succeeding winter was much milder than the preceding one. There was no complete ice cover on White Oak Lake during that period. The summer of 1952 was drier and hotter than the preceding one and the drought that year became one of the worst in local history. The fall was also dry and the ensuing winter was mild. Again, there was no complete ice cover on White Oak Lake. The spring of 1953 was about normal, but by July the signs of a drought, even more serious than the one of the preceding year, were in evidence. From this summary it is evident that the Survey was conducted during a period of generally adverse climatic conditions; the lake was excessively turbid most of the time and the summers and autumns were unusually hot and dry.

RADIOLOGICAL METHODS

All samples of tissues, both plant and animal, were prepared for radioassay in the laboratories of the Health Physics Division, Oak Ridge National Laboratory, by a modification of the nitric acid wet-digestion method developed specifically for this program by Krumholz and Emmons (1953).

Those samples represented different tissues from the various kinds of plants and animals native to the drainage area of White Oak Creek, and any radioactivity in them was the direst result of normal metabolic processes. The sizes of the samples differed considerably, but in all cases an effort was made to obtain enough tissue to yield reliable results.

During the course of the Survey, a total of more than 25,000 samples were prepared for radioassay and counted. In general, the samples of plant material were counted for five minutes whereas those of animal tissue were counted for 20 minutes. All data are listed as gross beta radioactivity in counts per minute per gram (fresh weight) of tissue. All counting was done in the counting-room facilities of the Health Physics Division an the second shelf of an end-window Geiger-Mueller counter (scale of 64) at a geometry of approximately 10 per cent depending on the particular instrument used. Thus the numbers of disintegrations per gram are approximately 10 times the number of counts. The values for the amounts of radioactivity present (counts per minute per gram) can be readily converted to microcuries per gram by dividing by 2.22×10^5.

Radiochemical analyses of individual samples were performed by either A. H. Emmons or B. Kahn of the Waste Disposal Research Section, Health Physics Division. The more extensive work on radiochemical analysis was done in the laboratories of the Analytical Chemistry Division under the supervision of C. L. Burros.

In some instances decay and/or absorption curves were prepared from individual samples in an effort to determine the identity of the radionuclides present. Autoradiograms were prepared for many of the plant tissues in order to determine the main areas of concentration of radioactivity.

BOTANY

Any attempt to interpret the present flora is difficult because of the recent history of the area under consideration. The effects of fire, grazing, ond other disturbing influences have not been adequately investigated, and it cannot be said that all the normal elements of this portion of the Ridge and Valley Province are present. In fact, there is good evidence that some species of plants may already have been eliminated from the study area. Between August 1950 and June 1952, 38 species of bryophytes, referable to 31 genera and 19 families, together with 392 species of vascular plants referable to 258 genera and 91 families, were collected and identified. Individual specimens of each of those different plants were placed in collections of the following institutions: U. S. National Herbarium, Washington, D. C.; University of Tennessee, Knoxville; and Duke University, Durham, North Carolina.

The general survey of the area revealed no unusual conditions in the vegetation. The morphology of plants which grew in the areas most heavily contaminated with radioactive materials appeared normal in every respect. The ecological succession among the various species of plants around White Oak Lake and Creek showed no noticeable differences from that at similar sites near other reservoirs in the Tennessee Valley.

One unusual plant was collected from a clone of broad-leaved cattail (Typha latifolia) which had a variegated leaf pattern. That clone was growing in the Settling Basin at the Oak Ridge National Laboratory. Such a pattern of coloration is extremely rare in that species and it is believed that it may have been induced by the long period of exposure to the radiation from waste materials in the basin. However, when portions of that clone of cat-tail were transplanted to other locations which were relatively free from radioactive contamination, the variegated pattern was lost.

In order to determine the extent of accumulation and the locations of the primary areas of deposition of radiomaterials in the various plants throughout the study area, several methods, both qualitative and quantitative, were used. Autoradiograms were prepared from various tissues of a selected group of plants to ascertain in which tissues the greatest concentrations of radioelements were deposited. Samples of the various tissues of different plants from large numbers of individual samples, collected over a wide area at all seasons of the year, were assayed for gross beta radioactivity. Groups of samples from each of ten plants of the same species, growing in a limited area, were similarly assayed to determine the extent of variation between individual plants. In addition, radiochemical and spectrographic analyses were made on selected samples in order to identify the radionuclides which were concentrated.

The general results from the radiographic analysis were three-fold:

1. The concentrations of radiomaterials accumulated by plants were progressively smaller in amount from the Settling Basin downstream to the mouth of White Oak Creek. Samples of plants collected just below the basin provided good autoradiograms after an exposure of 24 hours (Figure 1), those from White Oak Lake after an exposure of 72 hours (Figure 2), and those collected below the dam showed no darkening of the film following an exposure of seven days.

2. The highest concentration of radiomaterials in the woody

Fig. 1--Autoradiogram following an exposure of 24 hours of the mature fruit of the elderberry (Sambucus canadensis).

Fig. 2--Autoradiogram following an exposure of 72 hours of the leaves of the fog-fruit (Lippia lanceolata).

plants near White Oak Creek was in the bark. Although the samples used in those autoradiograms contained wood that was formed by the trees prior to the time the area became contaminated with radiomaterials, there was no detectable gradient of radioactivity from the central part of the heartwood toward the outer edge. There was, however, a decrease in the amounts of radioactivity in the samples from the lower parts of the trees towards the tops.

3. The greatest concentrations of radiomaterials in the forbs and grasses were in the leafy portions of those plants.

In general, the results from autoradiography were corroborated by radioassay; the majority of the accumulated radioactivity was concentrated in the bark of the woody plants (Table 1) and in the leaves of the forbs and grasses (Table 2).

The results from radiochemical and spectrographic analyses indicated that all living plants are capable of selectively concentrating specific radionuclides. The following radioelements were most common among those specifically concentrated: strontium, cesium, ruthenium, rare earths, and zirconium. Radioanalyses of samples from individual specimens of the same species of plant from the same location indicated that there were considerable variations in the amounts of radioactivity concentrated from plant to plant.

In only one known instance was enough radiomaterial concentrated to cause apparent damage to the plant. The plant in question was an American elm tree (Ulmus americanus) that selectively concentrated enough radioruthenium to cause the edges of the leaves to curl and die (Figure 3). Microscopic sections of those leaves indicated that there was a sharp line of demarkation between the normal and injured tissue. The

Table 1. Average gross beta radioactivity (counts per minute per gram) accumulated in the tissues of 10 individuals of each of five kinds of woody plants.

Kind of plant	Bark	Wood	Leaves	Twigs
Smooth sumac (*Rhus glabra*)	87	21	44	53
Button-ball (*Cephalanthus occidentalis*)	113	3	14	10
Black willow (*Salix nigra*)	123	30	50	66
Ash (*Fraxinus pennsylvanica*)	73	13	19	18
Sycamore (*Platanus occidentalis*)	74	14	16	20

Table 2. Average gross beta radioactivity (counts per minute per gram) accumulated in the tissues of 10 individuals of each of four kinds of forbs and grasses.

Kind of plant	Lower stem	Upper stem	Leaves
Little ragweed (*Ambrosia psilostachya*)	59	63	116
Smartweed (*Polygonum* sp.)	82	108	209
Wild rye (*Elymus canadensis*)	35	23	89
Beggar-tick (*Bidens bipinnata*)	79	82	81

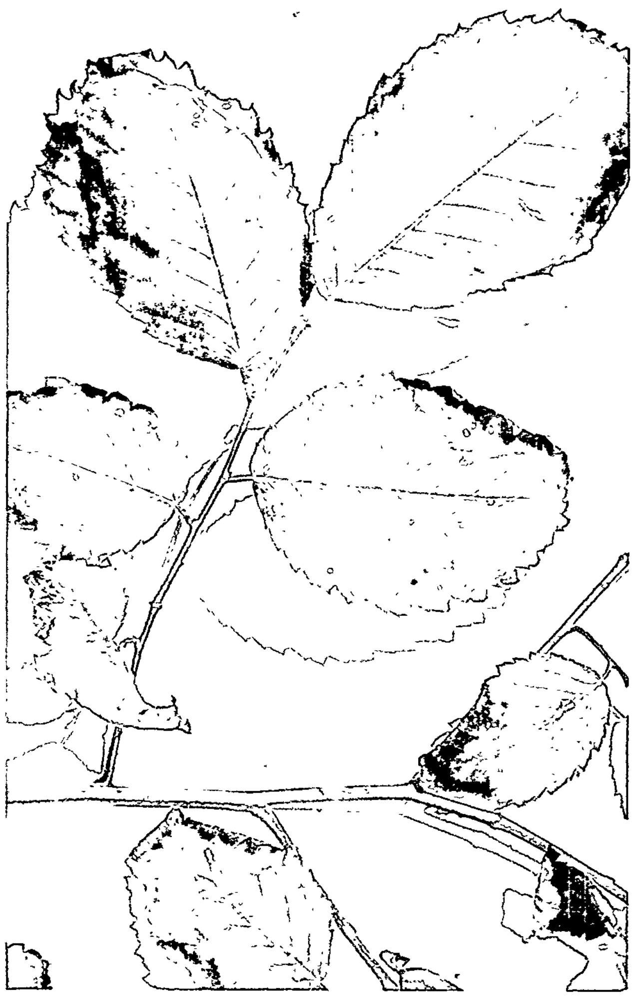

Fig. 3--Photograph of leaves from an American elm tree (Ulmus americanus) which shows the damage to leaves presumed due to irradiation.

injured tissue was considerably reduced in thickness apparently as a result of shrinkage of the palisade and mesophyllous cells. There was no detectable injury to the apparently normal cells of the damaged leaves. However, in that tree there was a consistent increase in the amounts of ruthenium in the twigs between late October and early May, which provided good evidence that solutes were continually absorbed throughout the winter months (Table 3).

It was found that there was no apparent correlation between the amounts of radioactivity in the soil and the amounts concentrated by the vegetation which grew in it as indicated by the data in Table 4. However, it was observed that parts of dead plants, which had fallen into water contaminated with radiomaterials, accumulated rather large amounts of radioactivity. Such accumulation is thought to have taken place primarily by adsorption in which the lattice structure of the plant acted as a sort of sponge. Analyses of living plants in a particular area indicated that they selectively concentrated certain amounts of specific radionuclides. Dead portions of those same plants which had fallen into the water contained considerably greater amounts of the same radioelements that were present in the living plants, plus an accumulation of the various radioelements present in the water that were not selectively concentrated by the living plants (Table 5).

After a laboratory analysis of soil from the lake bottom in which the mineral and organic fractions were separated, it was found that the organic fraction was capable of adsorbing much greater amounts of radiomaterials than the mineral portion. It was further determined that a mixture of Conasauga shale and dead leaves from trees was an effective filter for the removal of strontium-90 and cesium-137.

Table 3. Accumulation of radioactivity (counts per minute per gram) in the twigs of an American elm tree (Ulmus americanus) during the winter months.

Date of collection	Radioactivity
October 29, 1951	160
January 18, 1952	770
March 26, 1952	1000
May 2, 1952	1370

Table 4. Gross beta radioactivity (counts per minute per gram) accumulated in different tissues of 10 different plants of little ragweed (Ambrosia psilostachya) together with that in samples of soil taken near the base of each plant.

Plant no.	Leaves	Upper stem	Lower stem	Soil
1	210	120		3150
2	75	60	20	1950
3	100	50	75	930
4	100	70	45	170
5	15	15	10	1925
6	35	60	20	2960
7	120	25	100	2890
8	220	90	100	3210
9	130	60	70	925
10	150	75	70	4700

Table 5. Gross beta radioactivity (counts per minute per gram) in living and dead portions of broad-leaved cat-tail (*Typha latifolia*) and the water in which it grew, together with the percentage composition of the various radionuclides in the different samples.

Total radioactivity	Percentage composition					
	Ruthenium	Zirconium	Niobium	Rare earths	Strontium	Cesium
Live cat-tail						
1740	0.6	1.2	1.2	20.7	67.8	0.6
1580	0.6	1.3	0.6	21.5	68.4	0.6
2940	0.3	0.3	0	22.8	69.0	0
Dead cat-tail						
13,700	23.2	8.7	4.3	20.3	46.4	1.4
15,300	18.6	6.7	3.3	14.8	46.8	0.5
Water						
1620	45.7	1.2	1.9	13.6	47.5	1.2

LIMNOLOGY

Physico-chemical data for the water from White Oak Lake, which included determinations of chemical composition, dissolved oxygen, free carbon dioxide, total alkalinity, total hardness, ammonia nitrogen, nitrites, nitrites plus nitrates, hydrogen-ion concentration, total phosphorus, percentage of light transmitted, turbidity, temperature, and gross beta radioactivity, were collected routinely.

At times, usually during periods of algal blooms, the dissolved oxygen in the water reached or exceeded saturation. Similarly, at times the nitrate nitrogen reached a concentration of as much as 10 ppm. Such concentrations of nitrogen may well have been one of the major causative factors for the tremendous algal pulses which occurred periodically in White Oak Lake. In general, the following conclusions may be drawn from the physico-chemical data:

1. Sufficient amounts of nutrient materials were present at all times for the growth of plants, and occasionally there was a decided surplus of nitrate nitrogen.

2. Although relatively few determinations were made for ammonia nitrogen, there was no apparent problem of organic pollution. Results of analyses made on September 16, 1952 ranged from 0.209 to 0.388 ppm.

3. Values for total alkalinity (35 to 160 ppm), total hardness (60 to 390 ppm), and hydrogen-ion concentration (pH 7.10 to 9.55) fell within the expected range for waters in this area.

4. Enough bicarbonates were present to provide a continuous and adequate supply of free carbon dioxide for plant growth.

5. At no time was free carbon dioxide present in amounts large

enough to be deleterious to the aquatic fauna.

6. Temperature profiles taken at various times throughout the year showed the formation and disappearance of the thermocline over relatively short periods of time.

7. Turbidity of the water in White Oak Lake was caused primarily by suspended particles of clay. For the two years following June 1950, the lake was almost constantly turbid because of extensive earth-moving in conjunction with construction in parts of the watershed. The lake was relatively clear the third year, after the construction ceased and the large denuded areas were seeded and mulched. Turbiditywas a limiting factor in the production of rooted aquatic plants and attached filamentous algae, but apparently did not affect the reproduction and growth of the planktonic forms.

8. The amount of radioactivity per unit volume of water gradually increased during the three-year period although there were occasional, relatively great fluctuations from that line of increase. There was a general decrease in the amount of radioactivity in the water from the upper end to the lower end of the lake. In the deeper parts of the lake, the amounts of radioactivity usually increased from the surface to the bottom.

A total of 253 species of invertebrate animals, referable to 12 phyla, were collected and identified during the study period. That list is known to be incomplete. In addition, representatives of 93 genera of algae, referable to 6 classes, were identified.

Variations in the volume of total plankton in White Oak Lake followed the expected pattern of a bimodal curve with peaks in the spring and in the fall. The species composition of the plankton in the lake was similar to that found in nearby impoundments that had not been contaminated with radiomaterials.

The populations of some of the plankters were characterized throughout the survey period by tremendous, but usually short-lived, pulses as indicated in Figure 4. Such pulses lasted from two days, as in the case of *Chlamydomonas*, to more than a month with *Volvox*. Some pulses were local in nature, covering only a few acres, whereas others were more generally dispersed over the entire lake. Each species of plankton organism manifested its own characteristic pattern of pulse formation, and those distinguishing features did not differ appreciably from year to year. Organisms referable to the following genera were predominant among those causing plankton pulses:

Pandorina	*Carteria*	*Trachelomonas*
Volvox	*Pteromonas*	*Oscillatoria*
Chlamydomonas	*Euglena*	*Cryptomonas*
Chroomonas	*Difflugia*	

The most spectacular pulses were those formed by *Volvox*; about mid-May 1952, samples contained upwards of 700,000 colonies per liter. During such periods, the entire lake was deep green in color and was noticeably streaked with even greater concentrations of *Volvox*. Following such pulses, the zygotes of *Volvox* were so numerous that the lake became orange-red in color and, on one occasion, windrows of zygotes of *Volvox* were observed piled up along the windward shores.

Pulses of *Euglena* were almost as spectacular as those of *Volvox*. In those instances, however, the water was first a bright green in color, which, in turn, was followed by a yellow, a dirty yellow-brown, and finally a very deep brown that was almost black. The last stage produced

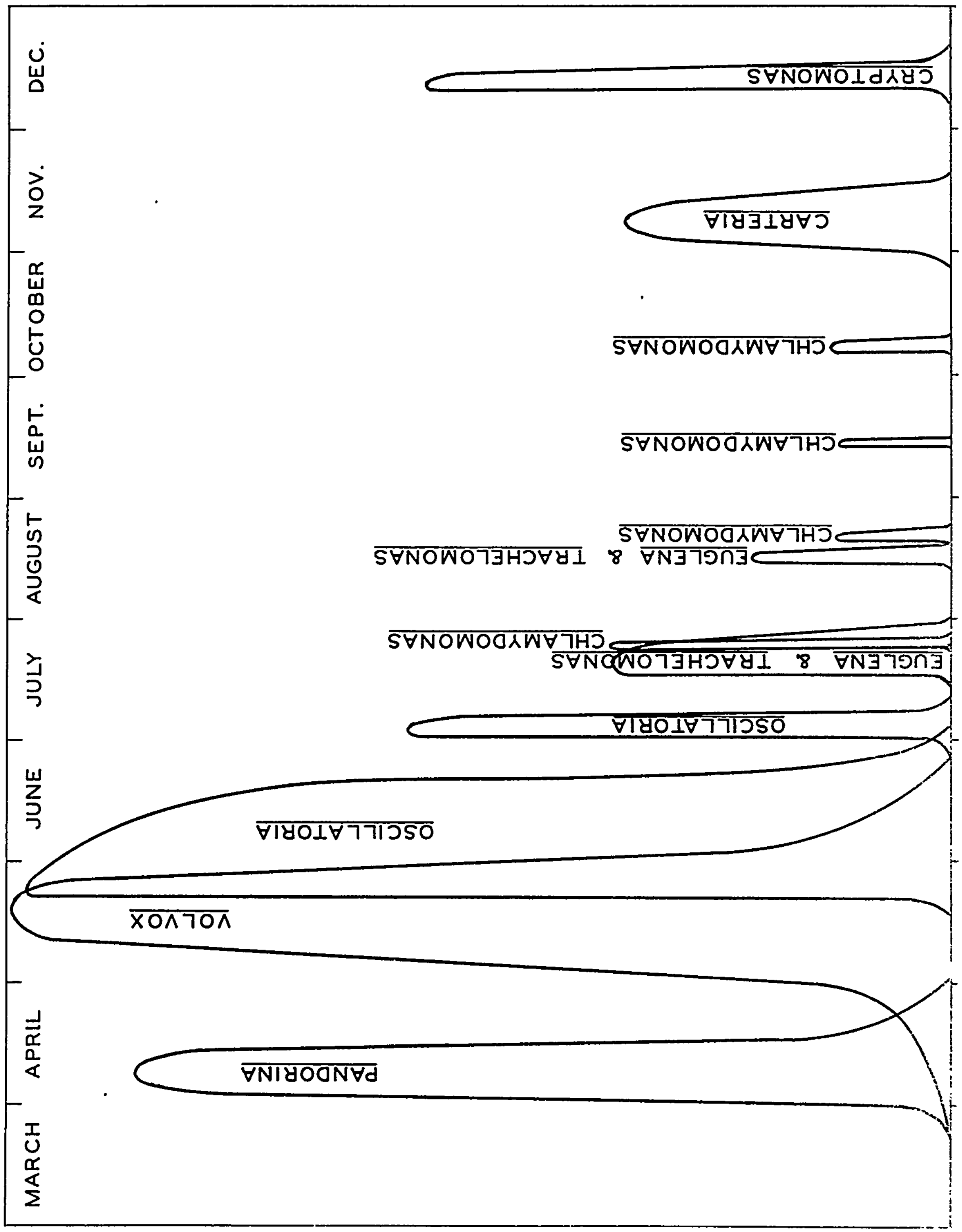

Fig. 4--Duration and relative abundance of plankton pulses in White Oak Lake, Roane County, Tennessee, 1952.

a film on the water which appeared not unlike one formed by used crankcase oil. In this last stage the organisms were encysted.

Phytoplankters accumulated radioactivity in fairly high concentrations; the maximum amounts accumulated by Volvox was 2800 counts per minute per gram; by Pandorina, 5700 counts per minute per gram; and by Euglena, about 2000 counts per minute per gram. Inasmuch as the average amount of radioactivity in the water of White Oak Lake approximated 10 counts per minute per gram, it can readily be seen that these phytoplankters concentrated the radioactivity by factors of several hundred. However, in each of the above-mentioned organisms, well over half of the radioactivity was emitted by radiophosphorus. Although no analyses have been made for radiophosphorus in the water from White Oak Lake, analyses for other elements in that water indicate that only a very small fraction (probably less than one per cent) of the total gross-beta radioactivity could be emitted by radiophosphorus. If half the radiomaterial in the plankters, and only one per cent of that in the water, is radiophosphorus, the concentration factor for that element is about 100,000 for Euglena, 140,000 for Volvox, and 285,000 for Pandorina.

The most abundant filamentous alga was Spirogyra. Mats of that alga frequently covered much of the bottom in the shallow upper end of the lake. This and other filamentous algae accumulated much greater amounts of radioactivity than the phytoplankton. The maximum amounts of radioactivity found in the filamentous algae (counts per minute per gram) were as follows: Oscillatoria, 6900; a mixture of Oscillatoria and Oedogonium, 15,650; and Spirogyra, 17,000. Radiochemical analysis of one sample of a large mat of Spirogyra, which covered much of the upper end of the lake, indicated that about 42 per cent of the radioactivity was emitted by radiophosphorus, 38 per cent by the rare ear s, and 20 per cent by radiostrontium. That entire mat, estimated to have weighed more than a ton, was believed to have contained well over 100 millicuries of radioactivity. When figured on the same basis as that used for the phytoplankters, the concentration factor for phosphorus in the *Spirogyra* was approximately 850,000.

The littoral bottom fauna was abundant and varied. The littoral zone of the lake, which included the area under less than three feet of water, was divided into five different types according to slope, kind of soil, abundance of organic matter, and relative productivity. Each of those five types supported similar organisms irrespective of the location in the lake. Larval dragonflies, damselflies, and other aquatic insects, together with adult aquatic coleopterans and hemipterans were common in the littoral zone. There was a direct correlation between the size of the various organisms and the productivity of the particular type of littoral zone. Midge larvae (Tendipedidae) were perhaps the most abundant organisms in the littoral zone but were also present in large numbers in the sublittoral zone.

The sublittoral bottom fauna consisted primarily of three species of organisms: *Tubifex*, larval *Tendipes*, and larval *Chaoborus*. *Tubifex* occurred in greatest abundance in the soft putrescent muds of the shallow portion of the lake whereas *Tendipes* and *Chaoborus* were more abundant in the deeper regions.

White Oak Creek below the Settling Basin supports a moderate population of benthos which consists primarily of *Tubifex* and larval *Tendipes*, along with limited numbers of mayfly, caddisfly, and other dipterous larvae, and a few mollusks. In White Oak Creek above the source of contamination, however, there were nearly twice as many genera represented in the collections. From such observations it is apparent that White Oak Creek, even in its lower reaches, is potentially a productive stream, but the effects of heavy siltation and the waste effluents from the Oak Ridge National Laboratory have inhibited that productivity.

Data from radioassay of samples of the various bottom organisms indicate that there is a good correlation between the type of bottom and the amount of radioactivity accumulated (Table 6). Because of the differences in habitat afforded by the five different types of littoral zone, the same kinds of animals did not inhabit all zone types. In addition to the correlation between the amount of radioactivity in the animals and the different types of littoral zone, there was a progressive decrease in the amounts of radioactivity in the bottom organisms from the upper end of the lake toward the dam (Table 7). This same pattern of accumulation of radiomaterials was exhibited by <u>Chaoborus</u>, <u>Tendipes</u>, and <u>Tubifex</u>.

*In most of the algae, plankters, and bottom organisms, radiophosphorus was selectively concentrated in greater amounts than any other radioelement. Based on the preliminary findings of this survey, it is probable that some organisms concentrated radiophosphorus by factors greater than 100,000. Such a conclusion seems to be justified inasmuch as concentration factors of approximately 80,000 were estimated without having taken into account the relatively rapid decay of radiophosphorus (half-life, 14.3 days). The time consumed in the routine preparation of samples for radioassay and the counting of those samples was three or four days (about one-fourth the half-life). In addition, other radioelements such as radiostrontium, some radioactive rare earths, and radiocesium were selectively concentrated by those organisms. Inas-

Table 6. Average gross beta radioactivity (counts per minute per gram) accumulated by four different kinds of organisms in four different types of littoral zone in White Oak Lake.

Organism	Type 1	Type 2	Type 4	Type 5
Anax junius	1640	1760	1790	2070
Belostoma sp.	1420	2420	2540	
Oreianthus sp.	2290	3330	5400	
Cambarus sp.	2220	2740	6190	

Table 7. Average gross beta radioactivity (counts per minute per gram) accumulated by three larval *Anax junius* and three adult *Belostoma* collected from each of eight locations, arranged in order from the upper end to the lower end, in White Oak Lake.

Station	Radioactivity in *Anax junius*		Radioactivity in *Belostoma*	
	per gram	per organism	per gram	per organism
South side of lake				
31L	2720	3920	2770	1800
26L	2080	2170	2550	1510
18L	1770	1280	2190	1460
7L	1850	990	1850	990
North side of lake				
29R	1590	1550	2630	740
53L	1490	930	1830	870
19R	1360	2000	1700	850
48L	1440	860	850	770

much as some of the phytoplankters serve as food for the zooplankters and bottom organisms, it is obvious that the radiophosphorus incorporated in the plankton algae was acceptable to the organisms which use them as food.

It is not surprising that deleterious effects were not observed on any of the planktonic forms. In order to make such observations, continuous detailed studies over a relatively long period of time would be required. For most plankters, the life cycle is so short and the reproductive potential so tremendous that, under ideal conditions, a relatively few organisms can irrupt into a spectacular pulse in a very short time. If the radiation to which the organisms in White Oak Lake were exposed continuously caused mutations that were lethal in character, a large fraction of the population could be decimated without having any unusual visible effect on the population as a whole. However, as will be indicated later, continuous exposure to irradiation, even at very low levels, will likely have a marked deleterious effect on the fitness of the population.

There are three primary conclusions which can be drawn from the observations on the accumulation of radiomaterials by the planktonic organisms in White Oak Lake: (1) radiophosphorus was concentrated in much greater amounts by both the zooplankters and the phytoplankters than any other radioelement but the concentration factor may nevertheless have been much greater for some radioelement other than radiophosphorus, (2) there was a gradual decrease in the amounts of radioactivity accumulated by all organisms from the upper end of the lake toward the dam, and (3) there was apparently a minimum of mixing of populations between the various parts of the lake. The second conclusion corroborates the findings of Knobf (1951) an the accumulation of radiomaterials in the fishes of White Oak Lake.

VERTEBRATE BIOLOGY

Individuals of 228 species of vertebrate animals, referable to five classes, were identified as follows: 23 species of fish, 14 species of amphibians, 17 species of reptiles, 158 species of birds, and 16 species of mammals. Although such a list appears to be rather comprehensive, it is not complete. No specieal affort was made to capture and identify amphibians, reptiles, and small mammals.

Six semiannual estimates of the size and composition of the fish population of White Oak Lake were made by the mark and recapture (fin-clipping) method according to the formula derived by Schnabel(1938). The following species were considered in those estimates: bluegill (Lepomis macrochirus), black crappie (Pomoxis nigro-maculatus), white crappie (P. annularis), largemouth black bass (Micropterus salmoides), carp, (Cyprinus carpio, goldfish (Carassius auratus), bullheads (Ameiurus natalis and A. nebulosus), and redhorse (Moxostoma aureolum). No estimates were made for the gizzard shad (Dorosoma cepedianum) because that species is so delicate that it cannot withstand the necessary handling. During these studies, only those fish large enough to be retained by the nets were considered. No attempt was made to estimate the numbers of small fish present. Although there were relatively large numbers of various species of minnows present in the White Oak Creek system, there were none in White Oak Lake with the exception of the carp and the goldfish.

Immediately following the last semiannual netting study, the lake was treated with emulsifiable rotenone in an attempt to check the validity of the netting estimates. Here, a special attempt was made to pick up all of the dead fish and to recover as many of the fish marked during the last netting study as possible. Thus, by knowing the numbers of each species of fish marked during the netting study and the numbers of marked fish recovered during the rotenone study, a fairly reliable estimate of the total number of fish in the lake could be made.

The estimates from the netting studies (Table 8) indicated that, in general, the fish population exhibited fluctuations in number and total weight which were well within the expected range. The total weight of the population decreased during the winter months, and that lost weight was usually regained during the ensuing summer. Also, there was evidence from the netting studies that two species of fish, the white crappie and the redhorse, were gradually disappearing from the lake. Another aspect of those studies revealed that the black crappie was more than twice as vulnerable to hoopnetting as the bluegill.

However, for some unknown reasons, the nets did not fish as efficiently during the last two netting periods as during the first four. Hence the reliability of the last two estimates for all species, with the exception of those for the black crappie and possibly those for the bullheads, is questionable. The last two estimates of the size of the black crappie population were believed to be as accurate as any because those fish were caught, marked, and recaptured in numbers comparable to those of any of the previous studies and, furthermore, the estimates appeared to be in line with the others. In the final netting study, it was believed that the estimates for the numbers of white crappies and redhorse were reliable inasmuch as both species were thought to be disappearing from the lake. In all the other estimates during the last two netting studies, with the possible exception of those for bullheads in the fall of 1952, too few marked fish were recaptured to yield reliable results. Whereas at least half the numbers of black crappies, white

Table 8. Estimates of numbers and weights, in pounds, of each species of fish large enough to be taken in the nets during each of the six semiannual netting studies, together with the estimates of the total weight of fish, White Oak Lake, Roane County, Tennessee, 1950-1953. No estimates were made for the shad.

Kind of fish	Fall 1950		Spring 1951		Fall 1951		Spring 1952		Fall 1952		Spring 1953	
	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight
Bluegill	6,050	602	5,600	639	22,000	2,106	6,500	788				
Black crappie	2,860	451	2,200	254	5,100	865	2,700	516	5,075	1,117	1,810	410
White crappie	1,140	180	375	43	450	76	50	12			6	2
Largemouth bass	130	250										
Carp	6,450	3,450	4,825	1,549	2,550	1,790	3,100	2,062				
Bullheads	250	188	390	192	875	371	350	141	488	211		
Redhorse	375	375	145	145	115	115	75	78	55	60	28	34
Total	17,255	5,136	13,546	2,842	31,190	5,323	12,775	3,597				

crappies, and redhorse marked were recovered, only 21 per cent (10 of 47) of the bullheads and less than 8 per cent (48 of 622) of the bluegills which were marked and released were recaptured. Here, although the percentage of marked bullheads appears to be adequate, the actual number of fish handled was too small to serve as a basis for a reasonable estimate. The estimates of the numbers and the weights (pounds) of each species of fish large enough to be retained by the nets during each of the six semi-annual netting studies, along with the estimates of the total numbers and weights for all species, in White Oak Lake during the survey period are listed in Table 8.

Unfortunately, because of the poor fishing during the last netting study, the information necessary for a comparison of the estimated size of the population from that study with the observed size of the population recovered during the rotenone study, was not available. The estimate for black crappies during the spring netting period (1953) was the only one for a reasonably large population that was believed to be accurate (1810 fish), and was significantly smaller (29 per cent) than the population recovered from the lake a month later (2334 fish). In an earlier study, Krumholz (1944) found that the fin-clipping method for estimating the size of a fish population yielded fairly accurate results when checked with those of a rotenone study. However, an analysis of the data obtained during the various studies at White Oak Lake points up the fallibility of the method. The numbers and weights of the fish large enough to have been retained in the nets used during the netting studies which were recovered during the rotenone study are listed in Table 9.

No white crappies and only 17 redhorse were recovered during the rotenone study, thus corroborating the evidence from the netting studies that those two species were disappearing from the lake. However, the reason for the gradual disappearance is not immediately obvious. Perhaps the most reasonable explanation is to be found in some slight change or changes in environmental conditions. Such a change could not have been drastic or the population would probably have been wiped out at once. Rather, the change was very likely one to which neither species could completely adapt itself and thus the well-being of the populations as a whole gradually deteriorated. It is also quite likely that the constant exposure to external and internal radiation, although at relatively low levels, could have had a deleterious effect. Such an occurrence does not seem unlikely. However, many of the normal processes of population dynamics among the closely related species did not appear to be adversely affected.

The growth and relative abundance of individuals of the various year classes reflect the general well-being of a fish population, and the ability of the different species populations to maintain themselves. During the netting studies, the lengths of all fish handled (more than 23,000) and individual weights from representative samples of all size groups of the different species (approximately 4000 individual weights) were recorded. Such data served as reliable bases for establishing length-frequency distributions and length-weight relationships. In addition, scale samples from nearly 2000 fish were analyzed in an effort to determine the age and rate of growth of the various year classes of the different species.

When these data for the individual species, as well as for the population as a whole, were analyzed and compared with the findings of Eschmeyer _et al._ (1944) and Stroud (1948,1949), the following conclusions may be drawn:

1. The rate of growth of all species of fish in White Oak Lake was

noticeably slower than that for similar species in nearby TVA impoundments.

2. The life spans of the black crappie and the largemouth black bass, and perhaps other species as well, were as much as 25 per cent shorter than those of the same species in nearby TVA waters.

3. Individuals of all species of fish increased in length during the winter months. This information corroborates that published by Krumholz (1948) for fish in experimental ponds in southern Michigan and northern Indiana.

4. The times of annulus formation for all species studied were similar to those of fish in nearby TVA impoundments.

5. Length-frequency data for all species of fish in White Oak Lake, except for the white crappie and the redhorse, were well within the expected range.

6. The length-weight relationships for the various species were much the same as those for the larger TVA reservoirs.

The food habits of the black crappies were quite different from those of the bluegills. Stomachs from 156 black crappies and 156 bluegills were examined. Of those, 50 of the black crappie stomachs and 56 of the bluegill stomachs were empty. The black crappies fed primarily on those macroplankters and bottom fauna which appeared as free-swimming organisms in the pelagic zone of the lake, whereas the bluegills were more omnivorous and generally foraged for food along the littoral zone. On an annual basis, 43 per cent of the total volume of the 106 crappie stomachs which contained food consisted of larval Chaoborus, an additional 20 per cent was made up of copepods and cladocerans, and 12 per cent was larval midges. Thus, about 75 per cent of the food of black crappies in White Oak Lake consisted of small invertebrate organisms -- only about 8 per cent was made up of small fish. The bluegills fed primarily along the littoral zone, and the variety of items found in the 100 bluegill stomachs which contained food indicated that they eat practically anything. Actually, there appeared to be very little preference shown for any particular kind of food; although 43 per cent of the annual total volume consisted of algae and the remains of vascular plants, it is believed that a large fraction of that material was eaten inadvertently. The four items which made up 75 per cent of the diet of the black crappies made up less than 25 per cent of that of the bluegills.

Radioassay of the contents of the stomachs of the black crappies and bluegills indicated that the food organisms had accumulated significant amounts of radioactivity. In the crappies, the amounts of radioactivity ranged from about 100 to 1800 counts per minute per gram of food whereas those from the bluegill ranged from 250 to 14,350; the average for the crappie stomachs was about 1000 counts per minute per gram and that for those of the bluegills was about 1250. The greater amounts of radioactivity in the contents of the bluegill stomachs was traceable primarily to the large quantities of filamentous algae.

Radiochemical analyses of the organisms which were most frequently found in the stomachs of both species indicated that most of the radioactivity was emitted by phosphorus-32, and that smaller amounts were emitted by radioisotopes of the rare earths, of strontium, and of cesium.

In order to set up a series of standard weights for each particular kind of tissue in the body of a fish, several individuals of each species in White Oak Lake were completely dissected and the component parts weighed. Each fish was dissected so that all the tissue which belongs to each of the following categories was recovered and weighed: scales, skin, muscle, compact bone, cancellous bone, fins, gill filaments, gill arches and rakers, eyes, stomach and pyloric caeca, intestine, heart, liver, gall bladder and contents, spleen, kidney, head kidney (pronephros), central nervous system, abdominal fat, gonads, and contents of the digestive tract. For example, all the muscle tissue (flesh) in the entire body was separated from all other tissues and weighed as a unit, and each of the other tissues was handled in a similar manner. No attempt was made to collect and weigh the blood or any of the other body fluids.

For determination of the percentage composition, the tissues were regrouped into stable tissues and variable tissues, based on the consistency of their occurrence in the body. Those tissues which were present in varying amounts, such as the contents of the digestive tract, the abdominal fat, and the gonads, were considered as variable tissues; all others were considered as stable tissues. In some individuals the digestive tract was fuller than in others, there was more fat in the abdominal cavity than in others, and the gonads of some fish were larger than others because the sizes of these organs change from season to season in relation to the reproductive cycle. In calculating the percentage of the total weight contributed by any tissue, the combined weights of all the stable tissues was considered as 100 per cent and the weight of each tissue was figured as a percentage of that total weight. From this information, several general conclusions may be drawn as follows:

1. Approximately the same percentage of the total body weight was contributed by the scaleless integument of the bullhead (8.1 per cent) as by the combined skin and scales of the black crappie (8.6 per cent) or by the combined skin and scales of the bluegill (8.2 per cent).

2. The percentage of the total weight contributed by the combined bony structures varied from species to species, presumably because of

differences in structural requirements, and ranged from 6.3 per cent in the gizzard shad to 13.9 per cent in the bullhead.

3. The percentage of the total body weight made up by muscle tissue was approximately the same for all species; the range was from 61.0 per cent in the bullhead to 70.4 per cent in the gizzard shad.

4. The relative sizes of the kidneys in all of the centrarchids (0.11 to 0.24 per cent of the total body weight) were markedly smaller than those in any of the other species (0,57 to 0.98 per cent).

5. The relative sizes of the livers in all of the centrarchids (0.8 to 1.2 per cent of the total body weight) were considerably smaller than those in any of the other species (1.9 to 3.7 per cent).

6. The relative weights of the eyes of the centrarchids, which feed largely by sight, were considerably larger (2.0 to 2.3 per cent of the total body weight) than those from the other species (0.2 to 1.2 per cent).

Inasmuch as one of the primary objectives of the survey was to deter- the kinds and amounts of radiomaterials accumulated by the fishes of White Oak Lake, individual fish were dissected and samples of the different tissues were prepared for radioassay. Results of preliminary radioassay revealed that fish collected during the summer of 1951 contained considerably greater amounts of radioactivity than those collected the previous winter. Accordingly, a year-round study of the accumulation of radioactive substances by fish in White Oak Lake was inaugurated, and three black crappies and three bluegills were dissected each week from September 1951 until February 1953. In addition, several specimens of each of the other species of fish in White Oak Lake were assayed for radioactivity.

Radioassay of the tissues from the black crappies and the bluegills, on a year-round basis, indicated that the following conclusions may be drawn:

1. Every fish assayed had selectively accumulated radioactive materials in their tissues far in excess of the amounts which occurred in the water in which they lived.

2. The primary radioelement concentrated in the soft tissues was cesium.

3. The primary radioelements concentrated in the hard tissues were strontium and, to a lesser extent, phosphorus.

4. The black crappies generally concentrated considerably greater amounts of radioactivity in the hard tissues, a ratio of about 5 to 3 (see Fig. 7), than did the bluegills.

5. The bluegills generally concentrated considerably greater amounts of radioactivity in the soft tissues, a ratio of about 3 to 2 (see Fig. 7), than did the black crappies.

6. In both species, the amounts of radiomaterials accumulated in the skeleton frequently were as much as 40 or 50 times as great as those accumulated in the muscle tissue.

7. There were definite seasonal fluctuations in the amounts of radiomaterials accumulated in the different tissues in both the bluegill and the black crappie as indicated by the curves in Figs. 5, 6, and 7.

The seasonal variation in the accumulation of radiomaterials in the fish tissues is largely governed by the seasonal changes in temperature which, in turn, control the metabolism of the animals in question. However, after the peak concentration had accumulated by midsummer there was a sharp decrease in the amounts of radiomaterials retained in the tissues by both species even though the water temperatures remained relatively high. Thus it appears that there is good preliminary evidence of a physiological nature that the fish in White Oak Lake entered a period of aestivation during August, and that period continued until late September or early October. During the winter months the amounts of radiomaterials in the

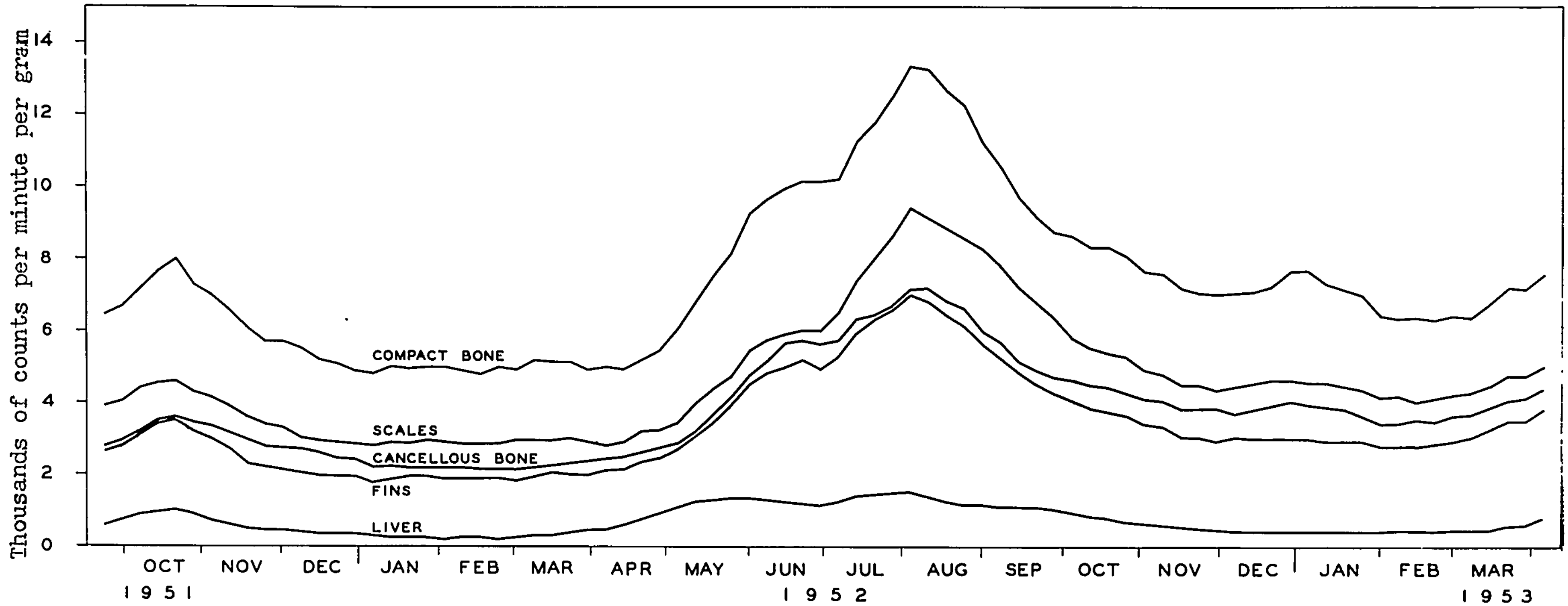

Fig. 5--Amounts of radioactivity, in counts per minute per gram, accumulated in five different tissues of black crappies collected from White Oak Lake between September 1951 and March 1953. The curves represent weekly averages which have been smoothed with a moving average of five.

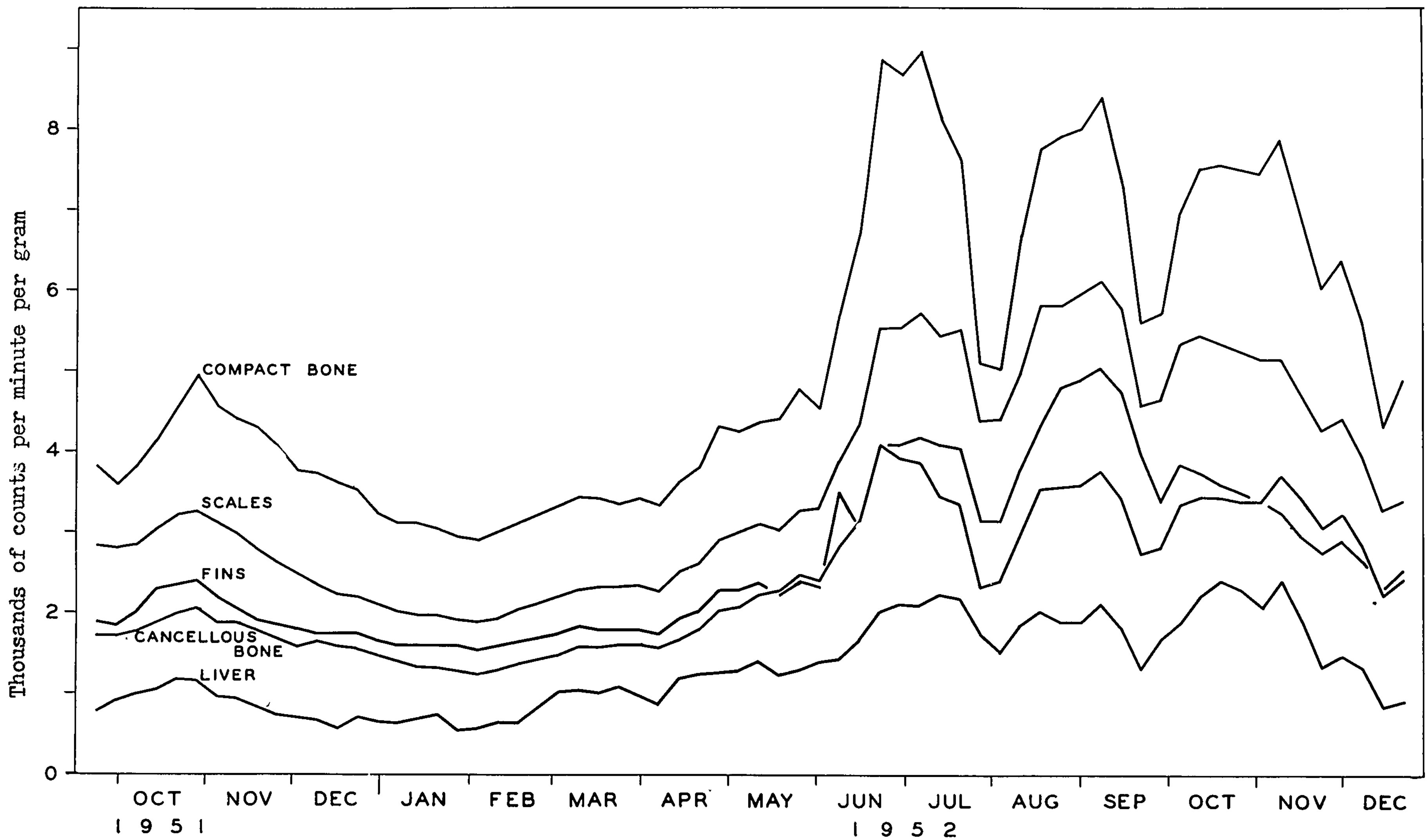

Fig. 6--Amounts of radioactivity, in counts per minute per gram, accumulated in five different tissues of bluegills collected from White Oak Lake between September 1951 and January 1953. The curves represent weekly averages which have been smoothed with a moving average of five.

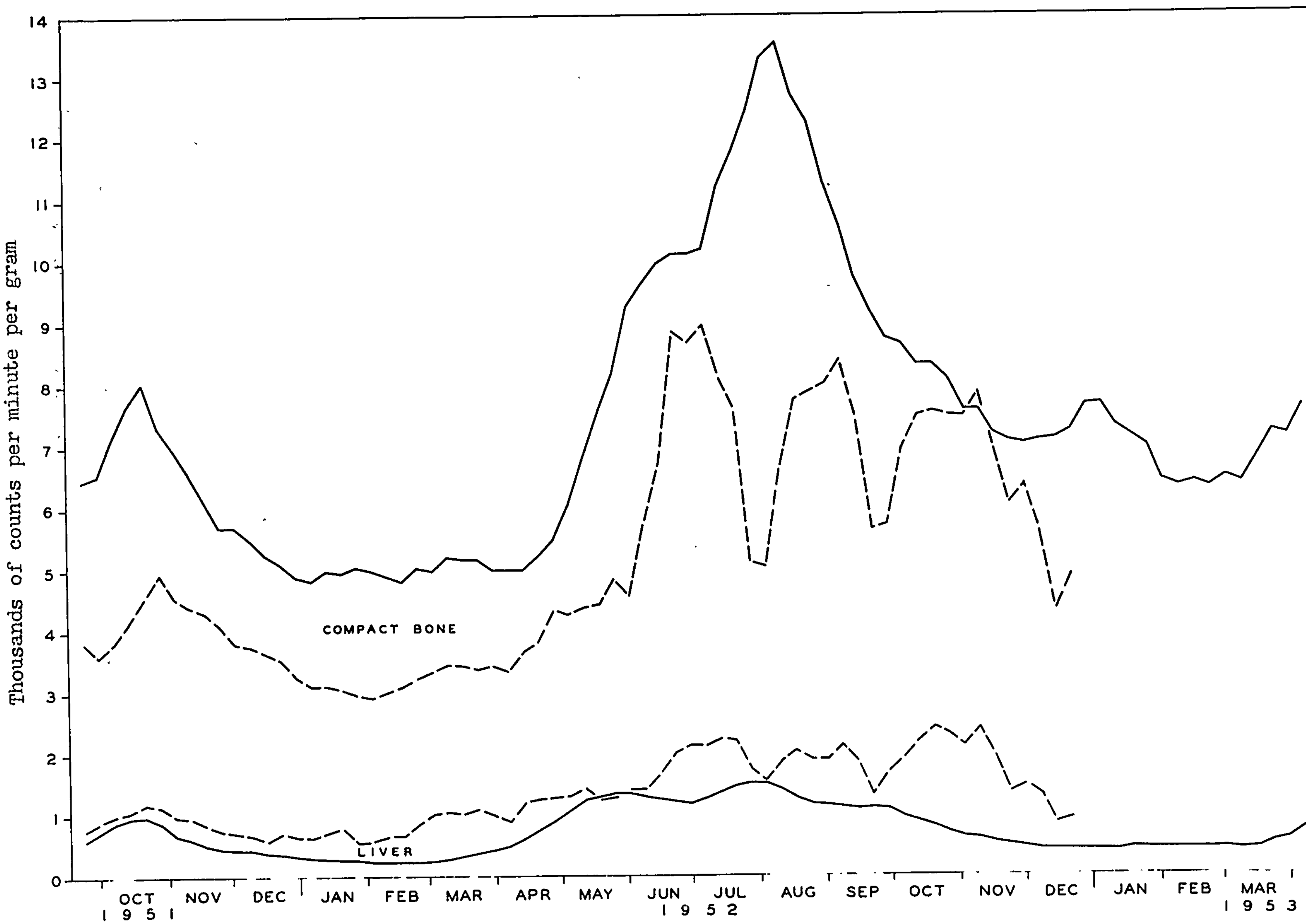

Fig. 7--Comparison of amounts of radioactivity, in counts per minute per gram, accumulated in each of two tissues of the black crappie and the bluegill. These curves are taken from Figures 5 and 6.

tissues remained fairly constant at a level about one-third to one-half that of the summer peak.

Although radiophosphorus was generally accumulated in much greater amounts than any other radioelements by the organisms which served as food for the fish, that element made up only a small proportion of the amount concentrated in the fish tissues, whereas strontium, which was present in the food organisms in only relatively small quantities, was concentrated in large amounts in the fish skeletons. Furthermore, although the contents of the bluegill stomachs contained more radioactivity, on the average, than those of the crappies, the crappies accumulated considerably greater amounts of radiomaterials in the hard tissues than did the bluegills. Both species of fish selectively concentrated radiostrontium in amounts 20,000 to 30,000 times as great as those in the water in which they lived.

From these and other data it is obvious that there are marked interspecific differences in the accumulation of radiomaterials by fishes, even between closely related species. It may be that the physiological requirements for the elements in question are different. If differences in physiological demands are so great between two such closely related species as the bluegill and the black crappie, any prediction of the relative amounts of radiomaterials that might be accumulated in the tissues of unrelated species would be pure speculation.

Tissues from other vertebrate animals, including 2 amphibians, 9 reptiles, 50 migratory waterfowl, 6 water birds, and 11 mammals were assayed and, in some instances, analyzed radiochemically. All the animals had been feeding on foods of their own choice that were native to the area.

Neither of the bullfrogs assayed had accumulated large amounts of radioactivity. All of the turtles had concentrated relatively large amounts of radiomaterials in the different parts of the skeleton. The various tissues of the snake contained very small amounts of radioactivity.

Although the herons and the kingfisher spent much of their time searching for food and feeding at White Oak Lake, none of the tissues contained very much radioactivity. However, the migratory waterfowl which fed primarily at White Oak Lake accumulated an average total body burden of at least five microcuries of radioactivity. Practically all of that radioactivity was concentrated in the edible parts of the birds, the muscle, skin, and giblets, and was emitted by phosphorus-32.

Among the mammals, the muskrats and the woodchuck accumulated more radioactivity than the raccoons and the squirrel. One of the muskrats concentrated more than one microcurie of strontium-90 per gram of bone throughout the skeleton -- a total body burden of nearly 100 microcuries (Krumholz and Rust, 1954). That animal had developed an advanced osteogenic sarcoma at the proximal end of the right tibiofibula, and the tumor cells had metastasized to both kidneys and both lungs. The woodchuck, although only a few months old, had apparently taken up its abode near the settling basin and had accumulated such large amounts of radioactivity in its tissues that it is believed it would have suffered the same fate as the muskrat if it had been allowed to continue living in the area.

A program of banding migratory waterfowl was inaugurated in September 1952 in order to obtain information on the movements of such birds that visited White Oak Lake. During the ensuing season a total of 649 water-fowl were banded and released and included: 390 mallards, 137 wood ducks, 96 black ducks, 17 coot, 6 pintails, 1 gadwall, 1 baldpate, and 1 green-winged teal. From these data and from general observations it was estimated that more than 6500 migratory waterfowl visited the lake that season.

Information on bands from ducks killed by hunters during that season was received from Tennessee, Kentucky, Alabama, Louisiana, and Texas. One of the banded birds was found dead in Haliburton County, Ontario, Canada, in April 1953.

DISCUSSION

A preliminary outline of an ecological study of the White Oak Creek drainage area was reported by Higgins (1950). At that time he outlined many of the studies that were intended for the Survey, but which were not carried out because of lack of time and/or personnel. In a later paper, in which some of the genetic effects of radiation were discussed, Higgins (1951) decried the emphasis placed by geneticists on the possible damage to the germ plasm of populations exposed to radiation. He stated that such changes in inheritance will be so small and so long delayed that they will have little significance from the conservation point of view. Inasmuch as the Survey has now been terminated, there is no chance to report on the long-term changes in the biota. However, many trends were observed, and it is believed that many important changes were taking place among the populations of aquatic animals.

The scope of the problem to be answered by the Ecological Survey of White Oak Creek is perhaps best outlined in a statement set forth by the Advisory Committee to the Survey at their meeting of January 27, 1950, as follows:

> "What radioactive elements have accumulated in living things in the stream; where have they accumulated; and what has been the effect on survival rates, population balances, and types of organisms?"

In order to obtain a reasonable answer to such a comprehensive question within the limited time allotted and with the limited number of personnel was impossible. However, much information was gathered during the three-year period, and indications of definite trends in changes in the balances of various populations were recognized. Although no intensive study was made of the reproductive potentials or the rates of survival of the various year classes of the different aquatic vertebrates, there were good indications that the over-all fitness of the populations was seriously impaired.

In an undisturbed animal community, there is a tendency toward a more or less stable equilibrium, from year to year, among the various components of the population. There are, however, natural seasonal fluctuations in population size, especially among the cold-blooded forms. Each of the various components of the population serves as a check and balance against the other components and, in turn, is acted upon by them. Many factors, such as space, climate, type of habitat, soil characteristics, and so forth, act as the physical limiting factors in the make-up of the population. The indefinite survival of any particular segment of the population depends largely upon the ability of that segment to adapt itself to changing conditions. Thus, if the climate becomes more and more moist, the xerophytic organisms must either adapt themselves to the increased moisture or they must move elsewhere. In a terrestrial community such a move may be possible although it is ordinarily not feasible; in an aquatic environment, where the boundaries of the community are sharply defined and the animal inquestion is unable to survive out of water, that animal must either adapt itself to any slight changes in environmental conditions, whether they are changes in hydrogen-ion concentration, average temperature, etc., or it will be unable to survive.

The changes within an organism which allow such adaptations to occur are usually genetic in origin. In an undisturbed population, there is a tendency toward an equilibrium between the number of mutations which arise during each generation and the number which are eliminated through death and/or non-reproduction. It has been shown by Muller (1927) and Stadler (1928) that the frequency of gene mutation in animals and plants can be markedly increased by exposure to X rays. Similarly, Auerbach and Robson (1944) showed that the exposure of Drosophila to such penetrating substances as mustard gas can also increase the frequency of gene mutations. It is well known that mutations which have been induced by such extraordinary means are indistinguishable from the so-called spontaneous mutations.

With a single exposure of an entire population, the maximum effect will appear in the first generation, and thereafter, without continued exposures the effect will gradually die away and disappear in succeeding generations. However, a continued exposure to a relatively constant source of internal as well as external radiation, such as that received by the animals in White Oak Lake, even though at a relatively low level, would tend to increase the number of gene mutations during each successive generation until a higher equilibrium value is reached. Thus there would result a greater accumulation of mutations within the population, and this would eventually lead to a higher genetic death rate. As the radiation continued generation after generation, the higher rate of genetic deaths would tend to reach a new and higher equilibrium with the higher rate of gene mutations, and the average fitness of the population for survival would be definitely lowered.

Muller (1950), in a resume of the damaging effects of irradiation to the genetic material, pointed out that each dose of 0.1 roentgen per day to an individual, whether spread out or concentrated into a short period of time, if followed by the normal ampunt of reproduction, would entail approximately a 10 per cent chance of killing some one descendant and of handicapping several or many descendants. Further, if this small amount of radiation represented the average dose received by the individuals of the whole population in every generation, that population would eventually come to suffer from about twice as many hereditary ills as if it had not been exposed. Auerbach and Robson (1946) found, upon exposure of male fruit flies to volatile mustard gas, that out of more than 1000 chromosomes, 7.3 per cent lethals were obtained as compared with only 0.2 per cent lethals in the controls.

Spencer and Stern (1948), in a study of the linear relationship between exposure to radiation and the frequency of gene mutation, stated that low dosages of X rays produce mutations which are as drastic in their effects and are in the same proportion to the doseage as those produced by higher dosages, and that there is no tolerance dose below which mutations are not induced. Those authors further stated that the total effect of irradiation on the germ plasm of a population of 100,000 individuals would be as great if each individual received one roentgen at the beginning of the reproductive period as it would be if only 1000 individuals had each received 100 roentgens and the other 99,000 had received none.

The total radiation dose that was received by any of the organisms in White Oak Lake is unknown. However, K. Z. Morgan (personal communication) estimated that, if the average concentration of radioactivity in the water is 10^{-3} microcuries per milliliter and the average effective energy is 0.3 million electron volts, the external dose rate is 1.1 rep (roentgen equivalent physical) per week. Thus some of the relatively long-lived aquatic vertebrates, such as the fishes and turtles, probably received the equivalent of more than 50 roentgens of external irradiation from the surrounding water each year during their entire life spans. Furthermore, those animals, because of their ability to concentrate radiomaterials in their tissues, received many times that amount as internal irradiation. All of the available food organisms were similarly exposed and all were contaminated with radionuclides. In addition to the radioactivity in the environment, the presence of toxic chemical substances must be considered.

In those animals which have a very short life span and reproduce very rapidly, such as the various zooplankters, it is difficult to determine through field studies alone whether or not any particular factor (e.g., constant exposure to radiation) had any deleterious effect on the population as a whole. Among such organisms, when conditions are suitable, a relatively few individuals can irrupt into a tremendous pulse within a few days. Similar irruptions among the phytoplankters are even more rapid and more spectacular. Such tremendous and rapid increases in population size are usually rather short-lived, primarily because of the limitations imposed by the environment which is unable to support such large numbers of organisms on a sustained basis. In the normal course of events, the organisms decrease in abundance until only the residual population remains. This residual population is usually only a very small fraction of the size of the peak pulse population.

Such tremendous fluctuations in numbers are not common among the larger animals. In fact, under normal conditions there is apparently a fairly good inverse correlation between the average length of the reproductive cycle and the amplitude of the fluctuations in population size; populations of animals with a long reproductive cycle (e.g., ungulates) very seldom irrupt into large numbers, whereas those of animals with a very short cycle (e.g., rotifers) usually irrupt several times each year.

Thus, although there were tremendous pulses both of zooplankters and phytoplankters in White Oak Lake each year during the survey period, no studies were made of the biotic potential of these organisms. It has been pointed out that White Oak Lake is an unusually fertile, and consequently a highly productive, lake presumably largely because of the primary-treated effluent from the sewage-disposal plant at the Laboratory. Plankton pulses are commonplace in very productive lakes. However, it is not known whether a lake of such productivity in this latitude might not produce even more spectacular plankton pulses if the environment were not radioactive or did not contain any toxic chemical substances. Without detailed information on the fecundity of adults, the viability of zygotes, and other vital statistics of the populations of the different plankters, it is vitrually impossible to determine whether or not there were any effects of the constant exposure of the population to irradiation. Pulses would, in all probability, continue to occur as conditions warranted such occurrence, even though the over-all fitness of the population was deteriorating. Controlled studies of populations of various plankton organisms would contribute much toward the solution of these problems.

It has been shown experimentally by Foster, et al. (1949) that exposure to x rays produced marked deleterious effects on rainbow trout (Salmo gairdnerii) in all stages of development from the fertilized egg to the adult. Some of the adult fish which had been exposed to 2500 roentgens were so extensively damaged that they died before spawning. Some of those same fish, which were partially mature when exposed to radiation, produced germ cells which had been irradiated during development within the parent fish. Ova obtained from adults which had received a dosage of 500 or more roentgens sustained a significantly greater mortality than ova from control parents, Most of the ova which died before hatching contained conspicuously deformed embryos. Such abnormal types of embryos occurred among the progeny of control parents, of parents which had received low dosages, and of parents which had received high dosages. However, as the amount of irradiation increased, the relative abundance of malformed embryos increased, and the degree of development attained by the embryos decreased. Practically all of the embryos from parents which had received dosages of either 1500 or 2000 roentgens were so abnormal that they died before closure of the blastopore. Thus there was a direct correlation between the dosage to which the parents had been exposed and the frequency of occurrence of malformations in the embryonic offspring. Among the offspring which had survived hatching, it was found that the growth during the first year of life was directly proportional to the amount of irradiation received by the parents. The growth of the progeny of fish which had received 100 roentgens was slightly less than normal whereas that of the progeny of fish which had received 500 roentgens was noticeably impeded.

It has already been pointed out that the rates of growth of the fishes in White Oak Lake were noticeably slower and the lengths of the life spans considerably shorter than those for the same species in nearby TVA waters. In addition, it was observed that two species of fish, the white crappie and the redhorse, although relatively common in 1950, had apparently been unable to maintain their populations and had gradually disappeared from the lake during the three-year period of the Survey; by April 1953, all of the white crappies were gone and fewer than 40 redhorse remained.

When these facts are considered in the light of the aforementioned studies on the effects of radiation on the genetic material, the circumstantial evidence against the continued (or increased) contamination of aquatic environments with radiomaterials is very strong. Although the evidence is not unequivocal that the damage to the populations in White Oak Lake was caused by irradiation alone, it can hardly be denied that the constant exposure to radiation may have been a strongly contributing factor. Any deleterious effects which may have been caused by the addition of untoward amounts of toxic chemical substances would have, in all probability, decimated the populations suddenly. Similarly, although any deleterious effects from increased turbidity would have been gradual, the turbidity of the waters of White Oak Lake was considerably diminished during 1952 and 1953 as compared to that of the previous two years.

It is strongly recommended that studies of the effects of radioactive effluents on wild populations of both vertebrates and invertebrates in the drainage basin of White Oak Creek should be continued on a long-term basis.

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In addition to the biological information provided by the Survey, data were obtained on sedimentation and water movement in White Oak Lake. The latter are provided in the following separate reports of the Tennessee Valley Authority:

Progress Report No. 1. Investigations of Water Movement in White Oak Lake and Creek. TVA, Hydraulic Data Branch. Feb. 9, 1951. pp. 1-7, 17 pls.

Progress Report No. 2. Investigations of Water Movement in White Oak Lake and Creek. TVA, Hydraulic Data Branch. June 22, 1951. pp. 1-3, 1 pl. pp. 1-5, 16 pls.

Investigations of Water Movement, August, 1951. White Oak Lake. TVA, Hydraulic Data Branch. pp. 1-9, 42 pls. October 30, 1951.

Sediment Investigation, White Oak Lake. TVA, Hydraulic Data Branch. pp. 1-3, 16 pls. June 30, 1953.

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